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THE INFLUENCE OF WOOD AND FIBER PROPERTIES IN MECHANICAL PULPING

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ABSTRACT:

Wood properties and wood quality have a large impact on the manufacture of mechanical pulps. Species density has been known to influence the energy requirements of pulping and the quality of the pulp produced since the turn of the century. Low density softwoods such as spruces are favored. Within a species, density also influences both energy requirements and pulp quality, but in this case, higher density wood from mature trees is generally preferred. To understand the anomalous behavior of wood density in refining, it is necessary to consider how wood density varies between and within species and to understand how energy is distributed to the wood in a disk refiner. Average fiber dimensions appear to control the energy required to create usable fiber surface area from the wood, but the variation in wood properties within the annual growth increment appears to control the way energy is distributed to the wood and the efficiency of energy use in refining.

INTRODUCTION:

One focus of Mechanical Pulping research at the Institute of Paper Science and Technology is to understand how wood structure and fiber morphology influence the specific energy requirements and pulp quality of stone groundwood and thermomechanical pulps. It is hoped that by better understanding how wood and fiber issues influence mechanical pulping, we can identify and propagate trees with improved mechanical pulping potential. Initial research attempted to define an average fiber parameter to quantify the mechanical pulping potential among several wood species.[1] Assuming the goal of mechanical pulping was to separate fibers intact at the S_1 layer, the pulping potential could be predicted by a parameter that measured average fiber surface area relative to fiber mass. This was simplified to average fiber circumference divided by the occupied cross sectional area (area occupied by the cell wall, excluding the lumen). An initial evaluation using a variety of sources of literature data suggested this ratio would give a straight line relationship when plotted against pulp breaking length at a fixed specific energy consumption.

$$R = (4\pi\bar{d}_f)/(\pi\bar{d}_f^2 - \pi\bar{d}_\ell^2)$$

where

$\bar{d}_f$ and $\bar{d}_\ell$ are the average fiber and lumen diameters

Efforts to prove this relationship failed. Mechanical pulp quality and specific energy requirements appear to depend on different morphological features when the comparison is made between different tree species than when the comparison is wood variation within a species. For example, within a species, high density variants generally give better pulp quality,[2,3] where on average, low density varieties are preferred when evaluating pulping potential among species (Figure 1).[4] The sensitivity of mechanical pulping processes to wood species and wood density has forced mills to exert significantly more control over the wood supply than the average kraft mill.

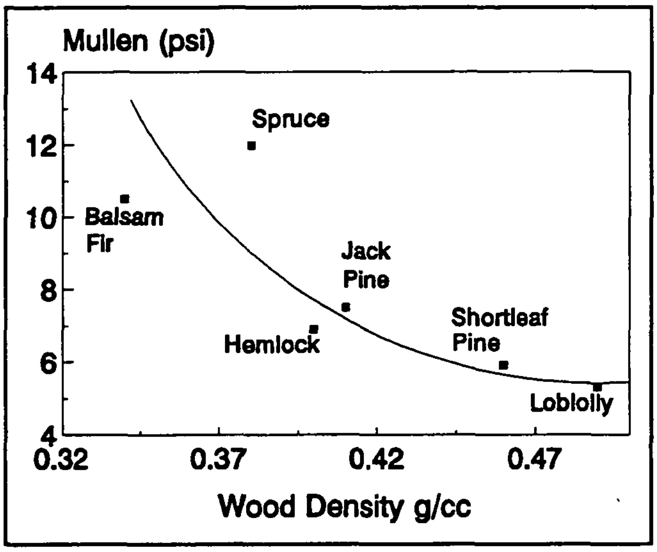

Figure 1. Mullen strength at 100 HPD/BDT plotted against wood specific gravity (dry weight over green volume) for various species.[4]

WOOD VARIATION:

To improve our understanding of how wood density influences refining within a species, an evaluation of the variation in wood and fiber properties was begun. Since the change in wood density within a species is largely determined by the relative amounts of earlywood and latewood,[5,6] the differences within an annual growth increment were emphasized. In Figure 2 are histograms for the fiber double wall thickness of typical red spruce and loblolly pine trees. The red spruce has a gradual transition to latewood which results in relatively few thick walled fibers. In comparison, loblolly pine has an abrupt transition to latewood which results in a bimodal distribution of fiber wall thickness. The latewood fibers account for nearly 30% of the tree volume and considerably more of the wood mass.

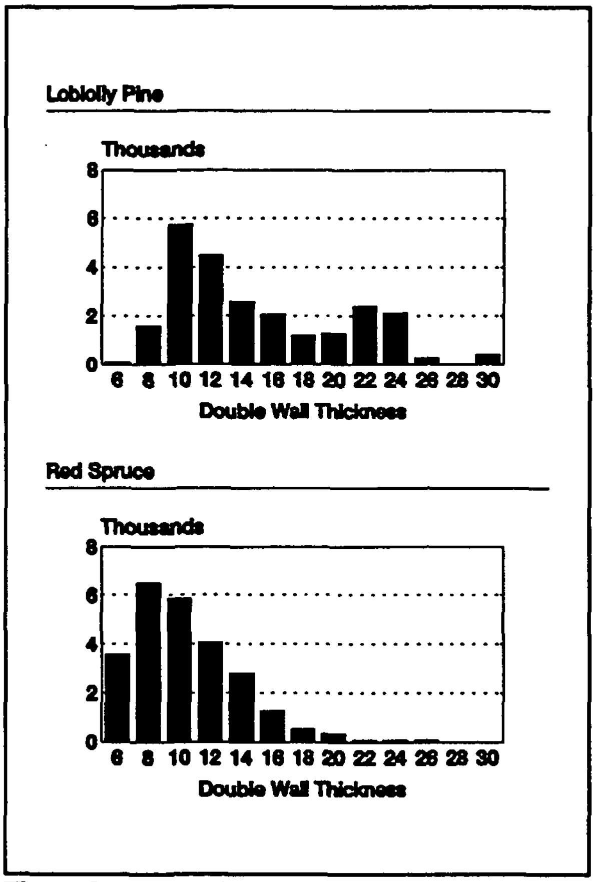

Figure 2. The distribution in fiber double wall thickness for a typical loblolly pine and red spruce.

Evaluations of the variation in specific gravity, parallel to grain tensile strength, and parallel to grain elastic modulus within an annual growth ring of Norway spruce and Shortleaf pine reveal interesting trends. Kennedy, evaluating juvenile (10 to 12 years) wood in 16 Norway Spruce trees found 20 to 25% latewood content with parallel to grain elastic modulus ranging from 0.4 X 10^6 psi in the first section of the earlywood growth zone to 1.4 X 10^6 psi in the final growth of the latewood.[6] Ifju, evaluating juvenile (8 to 10 years) and mature (18 to 20 years) shortleaf pines found about 50% latewood in the juvenile wood and a range in parallel to grain elastic modulus from 0.2 X 10^6 psi in the earlywood up to 1.2 X 10^6 psi in the latewood.[7] Similar differences are observed in tensile strength, with the juvenile shortleaf pine earlywood at 4,500 psi compared to a latewood strength of 22,000 psi and spruce earlywood at 5,800 psi increasing to 17,900 psi in the latewood. Within an annual ring, specific gravity ranged from ≈ 0.23 to 0.50 g/cc in spruce and 0.3 to 0.9 g/cc in the southern pines.

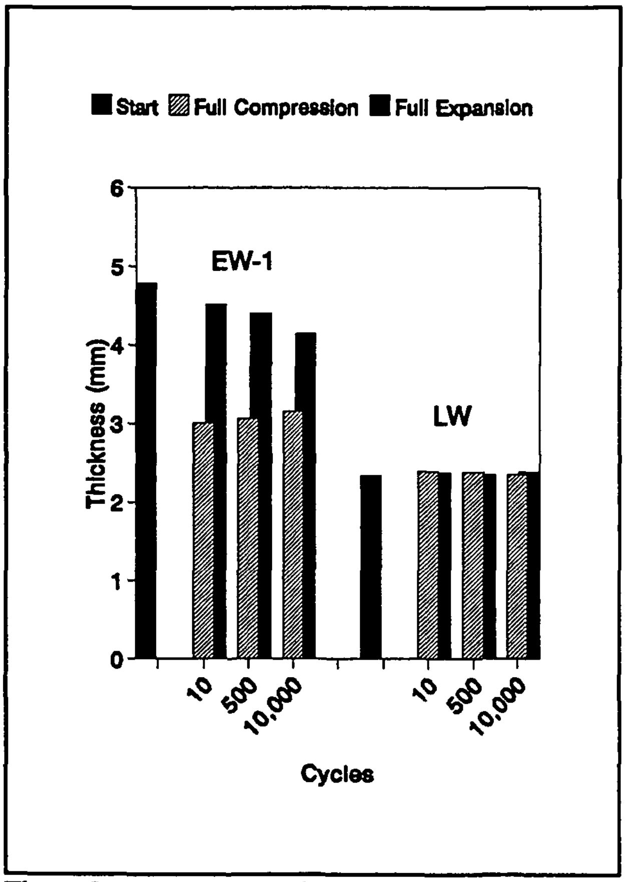

Figure 3. Compression of loblolly pine at 100° C and 1 Hz.

Of particular interest is the amount of latewood and the difference in strength and modulus between earlywood and latewood for the two studies. The shortleaf pine sample has nearly twice the latewood content of Norway spruce (on a volume basis) and the latewood in Shortleaf pine has 5 times the modulus of elasticity of the earlywood. In spruce, the latewood is just 3.5 times stiffer than the earlywood. Similarly, the shortleaf pine latewood has 4.9 times the tensile strength of earlywood. In Norway spruce, the latewood is just 3.1 times stronger than the earlywood.

SELECTIVE ENERGY ABSORPTION IN REFINING:

In the southern pines, the high latewood content and extreme difference in tensile strength and stiffness between earlywood and latewood creates a condition where the two growth zones are likely to behave differently in refining. A major mechanism controlling pulp quality in mechanical pulping is thought to be repetitive cyclic compression, which leads to fatigue failure in the fiber wall.[8] A wood mechanics study was initiated to determine how cross grain compressive stress was absorbed by loblolly pine. This work confirms the near total absorption of compressive stress by the earlywood portion of the annual growth increment (Figure 3).[9] Temperature measurement, taken during the cyclic compression experiments show a rapid temperature rise in the earlywood portion of the test piece, confirming preferential energy absorption by the earlywood portion of the growth ring (Figure 4).

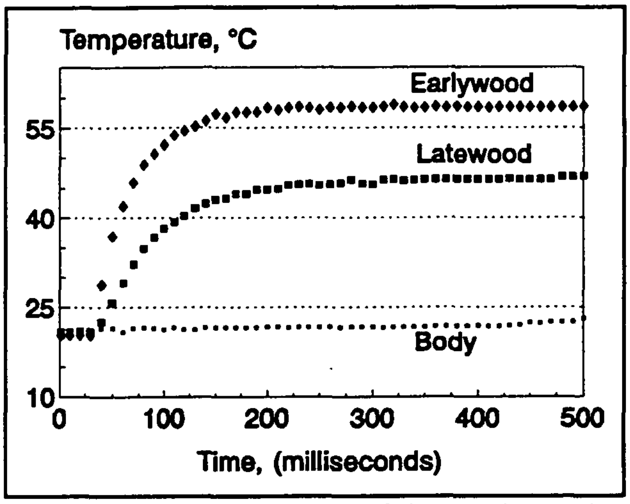

Figure 4. Temperature record of the sample tested at room temperature and 15 hz.

SELECTIVE FRAGMENTATION:

The logical consequence of the preferential stress and energy absorption by earlywood is that it will break up earlier in the refining process than the latewood. To determine if this happens in disk refining of loblolly pine, an analysis of changes in fiber coarseness of the different particle size fractions produced after low energy refining was carried out.[10] Wood chips were refined in a laboratory pressurized refiner at energy levels around 20 Wh/kg. The resulting coarse TMP was fractionated on a Bauer McNett apparatus using 4, 8, 20, and 100 mesh wire screens. Each fraction was pulped with acidic sodium chlorite and the coarseness was determined using the Kajaani FS100® optical fiber length analyzer.

As expected, the fiber coarseness changed with particle size fraction. The 4 and 8 mesh fractions have high coarseness values, typical of the whole wood. The 20 and 100 mesh samples have coarseness values close to that of an isolated mature earlywood sample.

Sample or Mesh	Coarseness mg/m	Fiber Length mm
EW	0.16	2.80
LW	0.38	3.26
4	0.22	3.21
8	0.21	2.41
20	0.17	2.62
100	0.18	1.21

Since the smaller particles are enriched in earlywood fibers, separating the large and small particles and refining each separately should allow a more uniform distribution of energy and stronger pulps than conventional refining.

Large samples of coarse mature wood and juvenile wood TMP were prepared. The sample was screened on a 10 mesh Swaco screen to collect R10 and P10 fractions.

Each sample was refined further in a Sprout-Waldron 12" Atmospheric Refiner. In addition to the fractionated samples, a mature wood sample and a juvenile wood sample were prepared from the same chips and refined as whole samples to provide controls.

Figure 5 shows a graph of Tensile index vs. specific energy consumption for the conventional juvenile and mature samples. This shows the expected relationship with the juvenile wood requiring about 15% additional energy to match the tensile index of the mature wood sample.[2] The tensile index for the juvenile pass 10 and juvenile retained 10 mesh samples are graphed against the mature whole sample in Figure 6. A line is not provided for the juvenile retained 10 mesh sample because the refiner plugged during one series of refining runs and several data points have unusually high energies. The most reliable data are the two points with tensile index near the juvenile pass 10 mesh samples.

For the fractionated juvenile wood cases, the tensile index of both samples is improved relative to the juvenile whole wood sample. The tensile index and specific energy

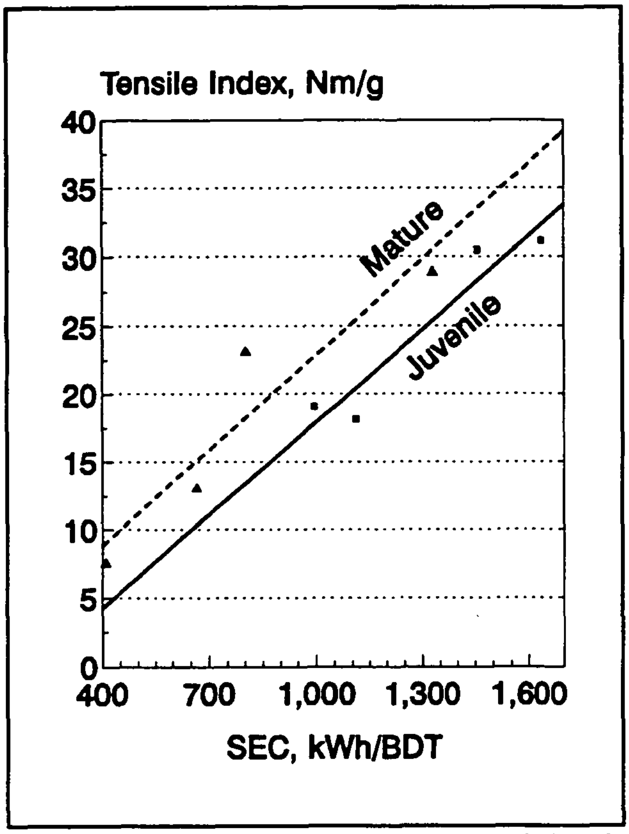

Figure 5. The tensile index for the mature whole pulp and juvenile whole pulp samples.

relationship for these samples is very close to the refining results of mature wood. This result was not obtained when mature wood TMP was prepared with interstage fractionation. With mature wood, the retained 10 mesh fraction developed the same tensile index specific energy relationship as the whole wood sample, and the mature pass 10 mesh sample showed low strength relative to the whole wood sample. It appears that the partial enrichment in earlywood makes the mature pass 10 mesh sample behave like juvenile wood.

CONCLUSIONS:

The mechanical pulping process has been known to be very sensitive to wood properties since 1937. A particular concern to southern mills is the relatively poor performance of the southern pines compared to spruce and fir. An initial attempt to describe the mechanical pulping performance of a species focused on an average fiber parameter. This was unable to explain the differences in mechanical pulp quality when wood age and density were varied both within a tree species and between tree species. More recent work is trying to understand how earlywood and latewood fragment in the refining process. This research has shown that early in the refining process, earlywood absorbs a majority of the refining energy and breaks down faster than the latewood. This inequitable distribution of energy may result in the low strength for mechanical pulps produced from low density (juvenile) southern pines. Fractionation after early stage refining appears to improve the performance of the juvenile wood, bringing it up to the level of mature wood.

Although this research has begun to determine how earlywood and latewood interact in mechanical pulping, it has yet to identify preferable morphological features for mechanical pulping. Continued research needs to focus both on the relative amounts of earlywood and latewood, and the difference in mechanical properties between earlywood and latewood in the southern pines.

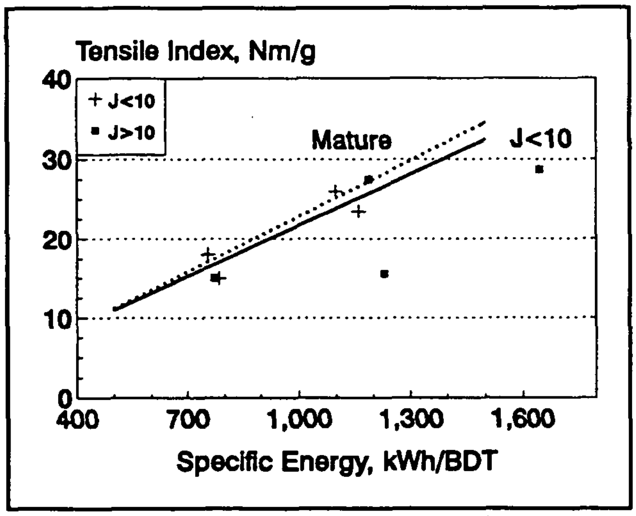

Figure 6. The tensile index data for juvenile pass 10 and juvenile retained 10 mesh samples plotted against the mature whole wood.

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REFERENCES:

1. Morra, J., "An Evaluation of Fiber Circumference Divided by Fiber Cross Sectional Area as a Measure of Mechanical Pulping," Independent Study Project, The Institute of Paper Science and Technology, March 1992.

2. McMillin, C.W., "Gross Wood Characteristics Affecting Properties of Handsheets Made From Loblolly Pine Refiner Groundwood," *TAPPI J.*, **51**(1): 51-56(1968).

3. Corson, S.R., "Influence of Wood Quality Characteristics on TMP and RMP From New Zealand Grown Radiata Pine," *APPITA* **37**(5): 400-408(1992).

4. Wynn-Roberts, R.I., "Grinding Characteristics of Various Woods," *Technical Association Letters* **XX**(): 258(1937).

5. Koch, P., *Utilization of the Southern Pines*, U.S. Government Printing Office, Washington, D.C., 1972, Vol. 1, p. 241.

6. Kennedy, R.W., "Intra-Increment Variation and Heritability of Specific Gravity, Parallel to Grain Tensile Strength, Stiffness and Tracheid Length in Clonal Norway Spruce," *TAPPI J.*, **49**(7): 292-296(1966).

7. Ifju, G., "Within-Growth-Ring Variation in Some Physical Properties of Southern Pine Wood," *Wood Science* **2**(1): 11-19(1969).

8. Salmén, L., Tigerstrom, A., and Fellers, C., "Fatigue of Wood-Characterization of Mechanical Defibration," *J. Pulp and Paper Science,* **11**(3): J68-J73(1985).

9. Hickey, K.L. and Rudie, A.W. "Preferential Energy Absorption by Earlywood in Cyclic Compression of Loblolly Pine," Proceedings, 1993 International Mechanical Pulping Conference, Poster Session, pp. 81-86.

10. St. Laurent, J.M., Rudie, A.W., and Shakhet, A.R., "Mechanical Pulping by Fractionation After Low Energy Refining," paper to be published this conference.